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WEAR ANALYSIS OF DIESEL ENGINE FUEL INJECTION PUMPS FROM MILITARY GROUND EQUIPMENT FUELED WITH JET A-1

INTERIM REPORT
BFLRF No. 272

By

P.I. Lacey

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The U.S. Department of Defense has adopted the single fuel for the battlefield concept. During Operation Desert Shield/Storm, Jet A-1 replaced diesel in many applications. A simultaneous increase in fuel injection pump failures was observed during that operation. Prior to its introduction, a number of studies had indicated that JP-8 is compatible with the current fleet of ground equipment. This report forms part of an ongoing study to define the fuel lubricity requirements of ground equipment. The report also details the wear and failure mechanisms observed from used pumps. The results indicate that, although Jet A-1 does increase wear, many other failure mechanisms are also prevalent.

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EXECUTIVE SUMMARY

Problems and Objectives: Increased failure rates associated with Stanadyne diesel fuel injection equipment operating on aviation turbine fuel were reported during Operation Desert Shield/Storm. A previous report detailed the wear/failure mechanisms associated with injector pumps from generator sets. However, a wider data base was required, and the current report considers pump models from a range of ground equipment, operating on both diesel and aviation turbine fuel.

Importance of Project: No recognized standard defining the lubricity requirements of the fuel injection system on compression ignition equipment currently exists. The present report details the wear mechanisms existing in lubricity-sensitive fuel injection equipment and forms part of an ongoing study of fuel lubricity.

Technical Approach: A number of failed pumps were obtained from Saudi Arabia and disassembled. Each of the wear-prone components from the pumps was examined in detail, irrespective of the failure mechanism. All fuel and contamination remaining in the pumps were removed and chemically analyzed. Three pumps from nonmilitary vehicles that operated on commercial diesel in the local San Antonio, TX, area were also studied to provide baseline data.

Accomplishments: The results obtained provide a more detailed understanding of both the failure mechanism and the wear process of the Stanadyne pump. In addition, minor differences in pump metallurgy appear to have an appreciable effect on the wear rate associated with the different pump models.

Military Impact: The results of this study indicate that several effects combined to promote increased failure rates of Stanadyne fuel injection pumps in Saudi Arabia. However, Jet A-1 does promote increased wear of certain critical pump components and, to some extent, may have been a contributing factor. Pump models designed for use on generator sets contain an improved metallurgy in critical areas of the pump and appear to be less sensitive to lubricity than models from wheeled vehicles.

FOREWORD/ACKNOWLEDGMENTS

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The author would like to acknowledge the efforts of BFLRF personnel, especially Mr. Rodney Grinstead, who provided both fuel injection pump expertise and a number of failed components for analysis. Messrs. J.J. Dozier, S.R. Westbrook, and D.L. Present provided chemical analysis, while Mr. D.M. Yost provided engineering assistance.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. INTRODUCTION AND BACKGROUND

The current report forms part of an ongoing study directed towards the effects of fuel lubricity on injection system wear. Of particular interest is the use of Jet A-1/JP-8 (MIL-T-83133) (1)* in overseas operations as an alternative fuel to diesel fuel (VV-F-800, Grade DF-2 OCONUS) (2).

A number of previous studies have indicated that kerosene fuels are compatible with the current ground tactical fleet. Nonetheless, recurrent problems have been reported with the Stanadyne rotary fuel injection pump, fitted to generator sets and certain vehicles such as the High Mobility Multipurpose Wheeled Vehicle (HMMWV) and the Commercial Utility Cargo Vehicle (CUCV).(3) Several factors associated with the 1990-1991 Operation Desert Shield/Storm exacerbated the problem. These factors include:

- Increased vehicle use
- Harsh desert environment
- Introduction of unauthorized fluids and oils as lubricity improvers
- Removal of fuel return valves or their modification
- Improper assembly of parts.

Moreover, some inherent design problems such as failure of the elastomer flex ring on the governor cage (on certain models) are likely to be present with either JP-8/Jet A-1 or DF-2.

Previously, a report was issued describing the failure mechanisms of "DB" series Stanadyne pumps from generator sets.(3) None of the failures could be conclusively attributed to the use of low-lubricity fuels. Rather, fuel contamination (i.e., water and particulates) and poorly fitting metering valve components were the primary cause of failure.

The operating conditions of model DB or DC rotary fuel injection pumps fitted to generator sets are likely to be very different from that of the DB2 pump associated with wheeled vehicles. The

* Underscored numbers in parentheses refer to the list of references at the end of this report.

DB2 model pumps are normally placed in the center of a Vee-configuration engine. This configuration will probably produce higher operating temperatures than that seen by the DB and DC models, which are mounted at the side of in-line engines. In addition, some of the pumps contained components adapted for use with low-viscosity/lubricity fuels, commonly known as "arctic" fuels. These differences are likely to affect the wear process and require further evaluation.

II. APPROACH

The current study concentrates on fuel injection pumps from a range of applications in Operation Desert Shield/Storm, including wheeled vehicles (i.e., HMMWV, CUCV) and generator sets. The DB and DC model pumps are used on 15-, 30-, and 60-kW generator sets, respectively, while the DB2 pump is commonly used on wheeled vehicles. A number of Stanadyne DB2 series pumps from nonmilitary passenger vehicles operating in the San Antonio, TX, area were also examined. These pumps had seen extensive use on diesel fuel and were used as a baseline for comparison with the military equipment that failed while using Jet A-1.

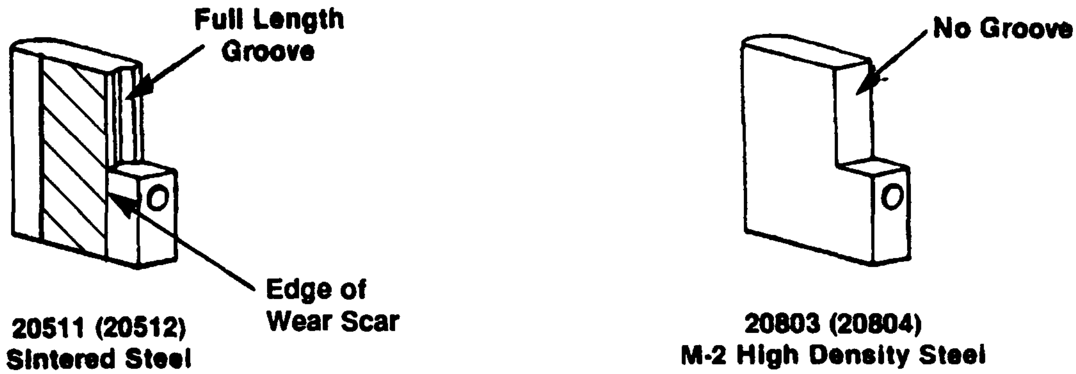
Schematic diagrams of the DB, DB2, and DC series pump configurations are shown in Appendix A. The mechanical configuration of the three pumps is very similar, although subtle differences exist between the DB, DC, and DB2 model pumps in both metallurgy and configuration. The manufacturer describes this pump as a single-cylinder, opposed plunger, inlet metering, distributor type. Power is transmitted to the pump by a removable drive shaft connected to the pump rotor through a drive tang. A weak point is provided in the drive shaft to protect the engine in case of pump seizure. Fuel is drawn into the unit by a positive displacement, vane-type transfer pump. During normal operation, a precisely metered volume of fuel passes from the transfer pump to the hydraulic head at relatively low pressure of less than 130 psi. The volume of fuel transferred is defined by a metering valve, the position of which is determined by the throttle setting and a centrifugal governor. Fuel is forced from the hydraulic head at high pressure by two plungers and is sent to the appropriate injector connection through a distributor rotor. The final component in the pump mechanism is a delivery valve that ensures a sharp fuel cut off at the end of the delivery cycle.

The DB and DC series pumps are designed to operate on low-viscosity/lubricity fuels. Critical components within the pumps have an improved metallurgy, corresponding to the "arctic" conversion for the standard DB2 pump. The upgraded components include the transfer pump liner and blades, the drive tang, and the governor thrust washer. The Rockwell hardness of a number of standard and arctic components is given in TABLE 1. The increased hardness of the arctic parts would be expected to decrease adhesive and abrasive wear, although its effect on corrosive wear is less well defined. Upgraded transfer pump parts may be distinguished from their standard counterparts, as shown in Fig. 1.

The transfer pump section was previously demonstrated to be particularly susceptible to wear.(3) As a result, the transfer pump was the subject of a more detailed study in the present work. A reciprocating motion is formed between the rotor and the transfer pump blade. This action forms a wear scar with a sharp step at the limit of the cycle, at the position shown in Fig. 1. The depth

TABLE 1. Rockwell Hardness of Standard and Arctic Components

Item	Standard Component (HRC)	Arctic Component (HRC)
TRANSFER PUMP		
Liner	43	63
Vanes	44	67
Rotor Retainer	51	--
HYDRAULIC HEAD		
Cam Ring	64	--
Roller	64	--
Shoe	67	--
ROTOR		
Drive Tang (DB2)	55	--
Drive Splines (DC)	55	--



a. Standard *b. Arctic*

Figure 1. Diagram of standard and arctic pump vanes

of the wear scar was measured at this step, using a Talysurf 10 profilometer. In addition, the surface roughness was measured across the sliding direction (parallel to the step). The profile was filtered with a cut off wavelength of 0.03 inches (0.76 mm) and a stilus tip dimension of 0.0025 mm. The results reflect the depth of the furrows ploughed in the surface of the blade by the wear mechanism.

In a previous study (4), the drive tang on DB2 series pumps suffered relatively severe wear. Loss of material in this area retarded the injection timing and caused reduced engine power. The drive tang on the DB and DB2 model pumps is replaced by a drive spline on the DC model. This modification distributes the drive load over a greater area and should help reduce wear, although the hardness of both parts is similar as shown in TABLE 1.

Each of the military pumps described in the current report had seized and could not be operated on a test stand. Complete disassembly was required in each instance. Fuel or debris remaining in the pumps was collected and analyzed as necessary. A number of the pumps had been previously disassembled, making effective analysis of any debris more difficult. In a previous study (3), large random variations in the diameter of the metering valve bore were the prime cause of pump failure. This problem was not observed on any of the current pumps. However, the diameters of both the metering valve bores and spindles were measured to allow further evaluation of this failure mechanism.

III. PUMP DESCRIPTIONS

A. Pump No. 1

Number:	AL-19627-X
Model No:	BO DB28929-4267
Serial No:	6594676
Mfg. No:	14077179
Outlet Ports:	8
Date:	February 1990
Remarks:	a. The pump was tagged with: Pump injector 2910-01-160-0613 Condition Code 14 Lot No. 6594864 Removed from CUCV b. Pump received from the U.S. Army Tank-Automotive Command (AMSTA-RGD)

This pump was provided to Belvoir Fuels and Lubricants Research Facility from Saudi Arabia and had been previously disassembled. The pump, manufactured in February of 1990, contained upgraded flex ring components.(5) Some fuel residue was present on the disassembled components. Gas chromatographic analysis indicated that the fuel was probably Jet A-1, with traces of a fluid with a higher boiling point distribution, such as engine oil. The boiling point distribution for the fuel is given in Appendix B, along with typical traces for both Jet A-1 and diesel fuels [ASTM D 975, "Specification for Diesel Fuel Oils" (6)].

The pump rotor was seized close to the transfer pump, with slight scuffing visible close to the pumping plunger end. However, the drive tang was not sheared, indicating that the seizure was accommodated by a failure of the gear train within the engine. The manufacturer's service bulletin (7) indicates that seizure at this location is normally due to excessive side thrust in the transfer pump. The complete transfer pump assembly was severely worn and a relatively deep wear scar (17 micrometers) was measured in the side of the pump vanes. Some circumferential scratches were visible on the transfer pump liner, but no evidence of scuffing was present.

The remainder of the pump was relatively clean and free of corrosion, both internally and externally, and the check valve was missing. No fatigue pitting or abrasive scratches were visible, and the inlet filter screen was clean (although it may have been cleaned on disassembly). The pressure-regulating piston as well as the pump blades and liner had a strong copper color close to areas of wear. The transfer pump liner is copper infiltrated; however, the present pump is fitted with standard blades that do not contain copper. The discoloration was also present on wear-prone surfaces remote from the transfer pump, such as the drive tang and the metering valve. Such discoloration is unlikely to be due to copper from the transfer pump area.

In contrast to the transfer pump, the hydraulic head has suffered relatively mild wear. The cam ring and advance piston were almost unworn. The delivery valve, which was a source of trouble in Stanadyne pumps from generator sets (3), also appeared new and unworn.

B. Pump No. 2

Number:	AL-19635-X
Model No:	BO DB28294267
Serial No:	6594864
Mfg. No:	14077179
Outlet Ports:	8
Date:	February 1990
Remarks:	a. Fuel ports covered b. Pump disassembled c. Pump tagged with: Pump injector 2910-01-160-0631 Removed from CUCV d. Pump received from the U.S. Army Tank-Automotive Command (AMSTA-RGD)

The pump had been removed from a CUCV and had been disassembled prior to shipping. The unit was very clean, both internally and externally, and was manufactured in February 1990 for the supply system.(5) The pump rotor had seized close to the transfer pump, and the drive shaft was sheared. No wear was visible on the metering valve, advance mechanism, or governor, while slight wear was present on the regulator and drive tang. The transfer pump suffered much greater wear than the remainder of the unit, but was not severely worn. The blades were polished, with

a mild wear scar 3 micrometers deep. No contamination or moisture was present within the pump, and the inlet filter screen was clean. This pump also contained the upgraded (post-1985) flex ring assembly, and the complete check valve unit (not just the ball) was missing.

No reason for this seizure was evident. The pump was almost new, unworn, and free of contamination. However, the unit had been previously disassembled but not cleaned. Misalignment of the pump with the drive shaft or a stuck injector may have contributed to the failure.

C. Pump No. 3

Number:	AL-19671-X
Model No:	DB2829 4471
Serial No:	5334248
Mfg. No:	23500398
Outlet Ports:	8
Remarks:	a. Pump received from the U.S. Marine Corps in Saudi Arabia
	b. Solenoid removed
	c. Fuel ports open
	d. Pump tagged with: HWMV fuel pump DB2 (presumably means HMMWV) 2910011714636

This pump was received fully assembled, but with the solenoid removed from the governor housing. The mounting holes for the solenoid were open, which could have allowed contamination to enter the pump. The exterior of the pump was corroded and dirty. Some corrosion occurred after the pump was removed from the engine, since part of the drive shaft (protected by the engine during operation) was slightly corroded. The pump was relatively new, and the standard elastomer flex ring was not discolored. However, the complete fuel return valve, including the glass bead, was missing.

The rotor was seized close to the transfer pump, and the drive shaft was sheared. Slight discoloration of the rotor had also occurred close to the pumping plunger end. The transfer pump blades and liner were severely worn, probably equivalent in civilian vehicles to several hundred thousand miles of operation on diesel. The wear scar on the pump vanes was 32 micrometers

deep, with a Center Line Average (CLA) roughness of 1.21 micrometers. A Scanning Electron Microscope (SEM) micrograph taken at the edge of the wear scar is shown in Fig. 2. The step measured by the Talysurf profilometer may be seen toward the right of the figure. Longitudinal wear tracks were ploughed into the surface, and the very porous nature of the sintered material is clearly visible.

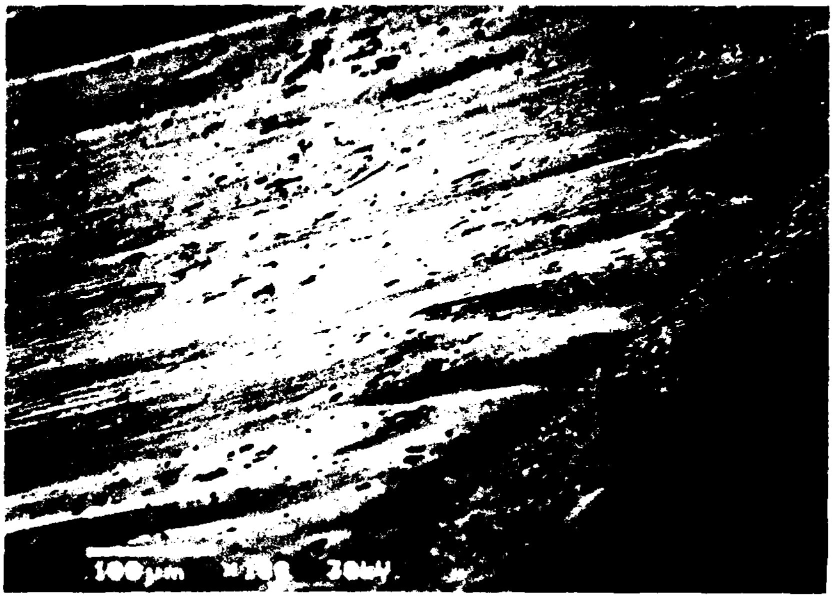
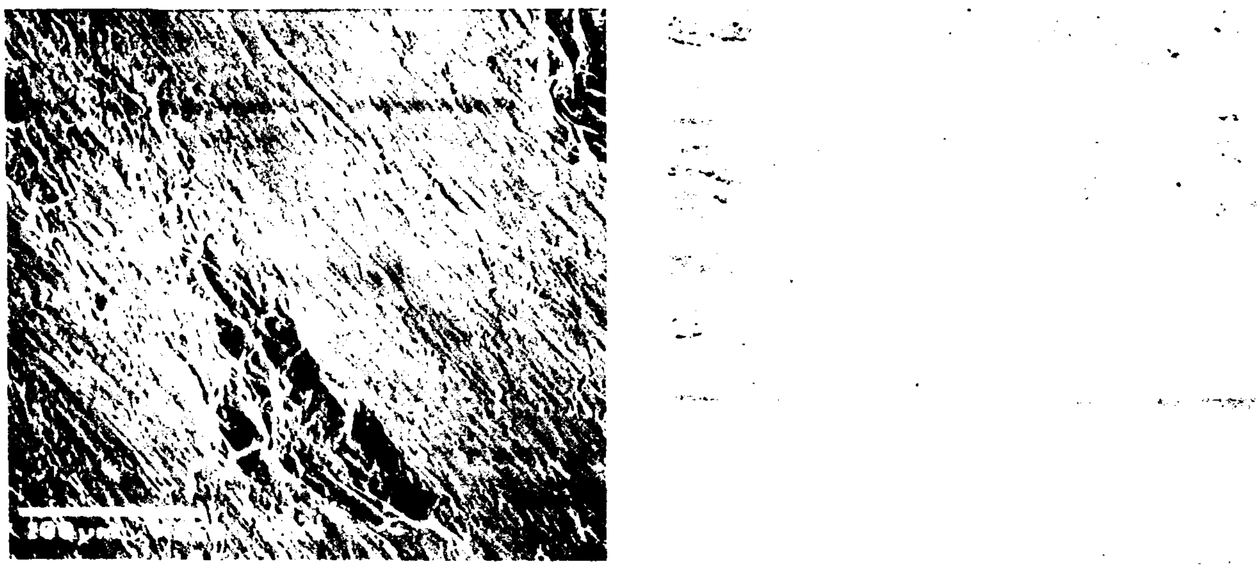


Figure 2. **<u>SEM micrograph taken at edge of wear scar on face of transfer pump vanes</u>**

The transfer pump liner was discolored at the area corresponding to the fuel outlet port. The surface topography in this area was slightly pitted, with some evidence of plastic deformation as shown in Fig. 3a. Elongated wear tracks were formed on the surface of the liner emanating from the scuffed area, as shown in Fig. 3b. These tracks were probably cut by adhesive wear debris that was formed during scuffing.

An accumulation of white powder was found on a number of parts including the inlet filter screen, cam ring, regulator, hydraulic head, and transfer pump. Because of its widespread distribution throughout the pump, it is believed that the contamination was present during operation (i.e., it did not enter through the solenoid mounting holes). X-ray analysis of the



a. Scuffed area close to fuel outlet

b. Worn surface away from outlet port

Figure 3. <u>SEM micrographs of transfer pump liner</u>

powder indicated that it consisted mainly of silicon and calcium, with traces of aluminum. The powder is probably an accumulation of airborne dust or fine sand particles and would almost certainly increase wear rate. As with Pump 2, severely worn areas had a copper hue.

D. Pump No. 4

Number:	AL-19672-X
Model No:	DB2829 4267
Serial No:	6120799
Mfg. No:	14077179
Outlet ports:	8
Remarks:	a. Pump tagged with: CUCV fuel pump DB2 2910011600613
	b. Fuel ports open
	c. Pump received from the U.S. Marine Corps in Saudi Arabia

The pump was received assembled, and the exterior was slightly corroded. As with previous pumps, the rotor was seized close to the transfer pump and the drive shaft was sheared. The transfer pump was badly worn (18 micrometers deep), and the liner was slightly discolored. A

small amount of metal had been chipped from the slots in the rotor, which retains the transfer pump vanes, as shown in Fig. 4. The location of the fractures coincided with the point of contact between the vanes and the rotor and was probably caused by severe side loading on the pump vanes. Such loading is known to cause seizure of the pump rotor.

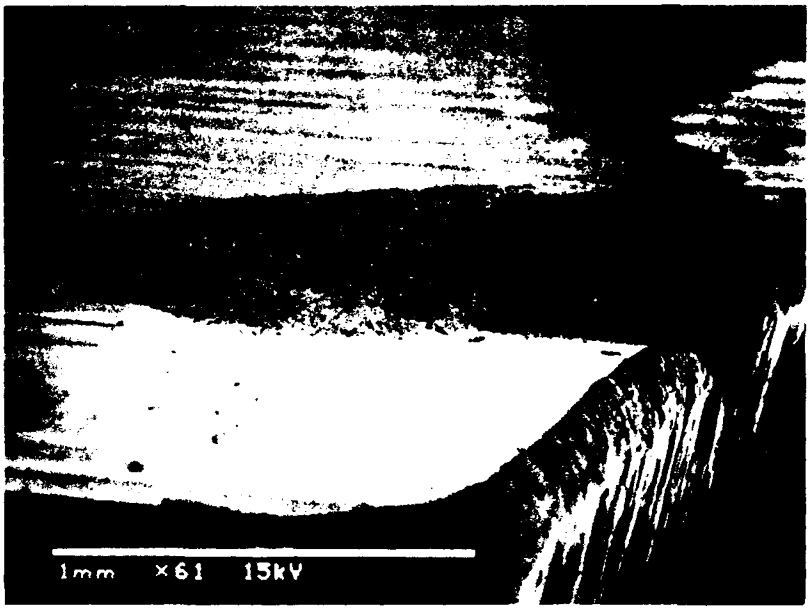


Figure 4. SEM micrograph of chipped pump rotor

Slight abrasive wear was also present on the cam rollers and shoes. A single scratch was around the complete circumference of each roller at the same location, probably due to an abrasive particle. No marks were visible on the cam ring. This wear should not be associated with the final failure mechanism since the hydraulic head is remote from the point of seizure.

Approximately 150 mL of pink fluid were removed from the pump during disassembly. The pink color could have come from MIL-H-6083 (8) and MIL-H-5606 (9) hydraulic fluids having been added. The fluid was of medium to poor lubricity and produced a Ball-on-Cylinder Lubricity Evaluator (BOCLE) wear scar of 0.65 mm. The boiling point distribution of the fluid was determined by gas chromatography. Again, the results indicated that the fluid was Jet A-1 or a very light diesel containing approximately 5 to 10 percent of an oil with a higher boiling point range. However, since no light diesel fuel was used in Operation Desert Shield/Storm, the fluid was probably Jet A-1. The standard (pre-1985 design) flex ring was new and flexible.

E. Pump No. 5

Number:	AL-19673-X
Model No:	DCMFC 629-2LQ
Serial No:	5806126
Mfg. No:	2910002282799
Speed:	1800 rpm
Outlet Ports:	6
Remarks:	a. The pump was tagged with: 2910002282799 MEP 115A fuel pump b. The pump was received from the U.S. Marine Corps in Saudi Arabia

This pump, which was used on a generator set, had been designed to operate on low-viscosity/lubricity fuel. The stock number provided for the pump indicates that it was used on an Allis Chalmers 3500 straight six engine. The pump was received fully assembled, with slight corrosion on the exterior surfaces. This corrosion probably occurred after the pump was removed from the engine, as the threads on the fuel outlet ports were corroded in a similar manner.

No drive shaft was provided, and the rotor was seized close to the transfer pump. Unlike previous pumps studied, the transfer pump was not severely worn; little visible wear was present on the vanes, and the contact area was smooth as shown in Fig. 5. As a result, no measurable wear scar could be located by the surface profilometer. The liner and retainers also showed little visible wear, although the liner was slightly blackened close to the outlet port. On the present pump (DC series), these components are fabricated from M-2 high-density steel, which corresponds to the arctic conversion kit for the DB2 pump.

One of the springs that maintain the position of the transfer pump blades had disintegrated, and the fragments were distributed throughout the pump. Loss of this spring may have caused the pump vanes to stick. In addition, fragments of metal from the spring may have interfered with the pump mechanism. The delivery valve spring was also broken, but the parts were contained within the valve. Seizure could be induced if the delivery valve stuck closed; however, the

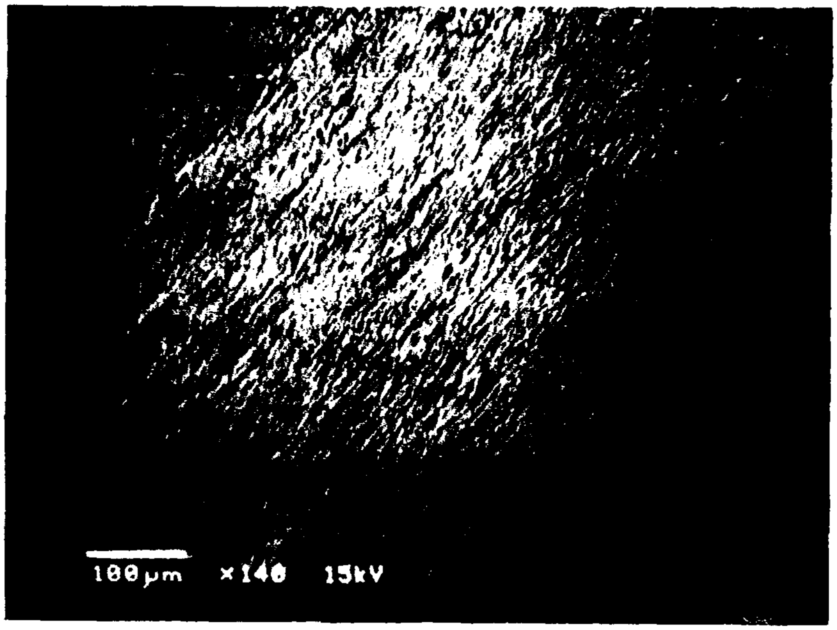


Figure 5. **SEM micrograph of worn area on upgraded (arctic) transfer pump vanes**

seizure would probably be located close to the pumping plunger end of the rotor. It is more likely that loss of the delivery valve spring resulted in a deterioration of the injection characteristics.

Most components in the remainder of the pump were severely worn and had seen high use. In particular, the metering valve and the delivery valve were severely worn. The elastomeric flex ring (standard pre-1985 design) was also badly degraded. However, the drive splines (which replace the drive tang on the DB and DB2 model pumps) were almost unworn.

F. Pump No. 6

Number: AL-19674-X
Model No: DBMFC-633-1LK
Serial No: 2013101
Mfg. No: 40-3050302
Speed: 1800 rpm
Outlet Ports: 6
Remarks:
- a. All fuel ports exposed
- b. Pump painted green
- c. Pump tagged with:
  MEP 114A fuel pump
  2910004990818
- d. Pump seized
- e. Drive shaft not sheared
- f. Pump received from the U.S. Marine Corps in Saudi Arabia

This pump was also used on a generator set and was designed to operate on low-viscosity/lubricity fuel. The exact date of manufacture is unknown, but was probably in the early 1970's. The stock number provided above indicates that the pump was used on a 30-kW generator set powered by a Hercules straight six engine. The pump was received fully assembled with the drive shaft intact, but seized. However, the fuel return valve was missing. The inside of the pump was severely corroded and would not have operated. Significantly, the outside of the pump was **not** corroded; indeed, the drive shaft was shiny outside the pump but rusted inside the pump. This condition would indicate that extended water contamination must have occurred before removal of the pump from the engine.

Although the pump rotor was not seized, some discoloration was present close to the transfer pump and the pumping plunger. This discoloration may have occurred if the pump were turned while stiff and corroded. The elastomeric flex ring (standard pre-1985 design) was degraded and dark and had become detached from the governor weight housing. The level of corrosion made study of the wear on the remainder of the pump almost impossible. The transfer pump parts were M-2 high-density steel (i.e., the arctic conversion kit), and no measurable wear scar was present. One transfer pump blade spring was broken, but this is to be expected with the level of corrosion present.

Pump failure was clearly caused by extended storage with moisture present in the pump.

G. Pump No. 7

Number: AL-19681-X
Model No: DB2829-4524
Serial No: 5775851
Mfg. No: 23500416
Outlet Ports: 8
Remarks:
a. Pump corroded on outside
b. Fuel ports exposed
c. Drive shaft sheared
d. Pump received from the U.S. Marine Corps in Saudi Arabia
e. Removed from HMMWV

The pump was manufactured in 1986 for use on an HMMWV and contained upgraded flex ring components (post-1985 design).(5) The outside of the pump was badly corroded with the inside slightly less so. Corrosion probably took place after the pump was removed from the engine. The pump rotor was seized close to, but not quite at, the fuel discharge ports on the pump rotor. However, the mating orifices in the pump body were slightly larger and were within the seized area. The manufacturer's service bulletin (7) indicates that this type of seizure is normally due to fuel contamination.

A number of grit particles were found within the pump, particularly around the advance mechanism. The inside of the nose cone had a layer of deposit, obviously formed during pump operation. X-ray analysis indicates that the deposit is primarily iron or rust with some calcium. The underlying metal did not appear seriously corroded.

The remainder of the pump contains a limited amount of wear. In particular, the advance piston and regulator were badly scored but were not stuck. The transfer pump was slightly worn. The pump vanes had a wear scar depth of 10 micrometers, with only mild wear visible on the rotor and retainers. The transfer pump blades were polished and had a surface roughness of 15 micrometers (compared to 37 for Pump 4). The typical parallel wear tracks seen on other pumps

operated with Jet A-1 (Fig. 2) were not present. This more polished surface is typical of that seen after operation with better lubricity fuel.

H. Pump No. 8

Number:	AL-19702-X
Model No:	DB2-4369
Serial No:	4983254
Mfg. No:	1807560-C91
Outlet Ports	8
Remarks:	a. Pump removed from nonmilitary vehicle operating in the local area (San Antonio, TX) b. 1983 Ford 6.9L van

To provide baseline pump data, this pump was removed from a civilian (i.e., nonmilitary) vehicle that operated on commercial diesel fuels throughout its lifetime in the Continental United States (CONUS). The pump failed due to fuel leaking from around the throttle shaft seal on the governor housing, causing the pump to lose its charge during long periods of shutdown. This pump is not the original part fitted to the vehicle and is believed to have been used approximately 80,000 miles.

The pump was in relatively good condition, and wear was evenly distributed. The transfer pump section was slightly worn, and no wear scar could be located on the transfer pump blades using the surface profilometer. In contrast to the remainder of the pump, the metering valve was severely worn. However, the seal produced by the metering valve was still sufficiently good to prevent engine run on.

The standard (pre-1985) elastomeric flex ring was brittle and degraded, but had not failed. No corrosion or contamination was visible.

I. Pump No. 9

Number:	AL-19701-X
Model No:	DB2-4102
Serial No:	4788597
Mfg. No:	1801359-C91
Outlet Ports:	8
Date:	1983
Remarks:	a. Pump removed from nonmilitary vehicle operating in the local area (San Antonio, TX) b. 1983 Ford 6.9L van

This civilian fuel pump was in good condition with the original factory seals still in place. This pump is believed to have operated for approximately 80,000 miles in CONUS conditions. Pump failure probably occurred due to degradation of the standard (pre-1985) elastomeric flex ring. The complete ring had disintegrated, and small particles of elastomer were dispersed throughout the pump. The check valve had been removed from the governor housing, and most of the ring probably passed to the fuel tank via the return line.

Again, wear was evenly distributed throughout the pump. No measurable wear scar could be located on the transfer pump blades using the Talysurf profilometer. In addition, no discoloration or evidence of scuffing was visible on the transfer pump liner. The advance piston and metering valve were the most highly worn areas of the pump.

J. Pump No. 10

Number:	AL-19700-X
Model No:	DB2829-4369
Serial No:	5441703
Mfg. No:	1807560-C91
Outlet Ports:	8
Date:	1984-85
Remarks:	a. Pump removed from nonmilitary vehicle operating in the local area (San Antonio, TX) b. 1984-85 Ford 6.9L truck

This civilian pump had operated between 60,000 and 80,000 miles in CONUS on commercial diesel fuel. The factory seals were still present, but the complete pump was slightly corroded both inside and outside. It is believed that this corrosion occurred while the pump was on the vehicle, as it had been in storage for some time. The standard (pre-1985) elastomeric flex ring was also broken, but not completely disintegrated.

The wear pattern present was very similar to that seen in the previous pumps that operated on commercial diesel; some wear on all components without an excessive amount in any one area. Again, the advance piston and the metering valve were the most severely worn areas of the pump.

IV. DISCUSSION AND COMPARISON AMONG THE PUMPS

The previous section described the disassembly and examination of seven pumps known to have failed while using Jet A-1 and three that failed while operating on commercial diesel. The failure mechanisms as well as the probable cause of failure in each instance are summarized in TABLE 2.

TABLE 2. Summary of Pump Failure Analysis

Pump No.	Failure	Cause	Comments	Fuel Related
		Jet A-1		
1	Seized Rotor	Excess Side Load	Transfer Pump Badly Worn	?
2	Seized Rotor	Excess Side Load	Almost New Pump	?
3	Seized Rotor	Excess Side Load	Contamination Present	No
4	Seized Rotor	Excess Side Load	Rotor Chipped	?
5	Seized Rotor	Broken Blade Spring	Arctic Conversion	No
6	Pump Corroded	Fuel Contamination	Arctic Conversion	No
7	Seized Rotor	Fuel Contamination	Seized at Discharge Ports	No
		Diesel Fuel		
8	Leaking Seal	Faulty Component	Mild Transfer Pump Wear	No
9	Broken Flex Ring	Faulty Component	Mild Transfer Pump Wear	No
10	Pump Corroded	Fuel Contamination	Mild Transfer Pump Wear	No

All but one of the seven pumps operating on Jet A-1 failed due to seizure of the pump rotor. In many instances, the cause of failure is self-evident. However, no clear cause of failure is visible in Pumps 1, 2, or 4. Stanadyne indicates (10) that seizure of the rotor close to the transfer pump may be due to a number of causes including:

1. Operating the pump at excessive speed
2. Incorrect pressure regulator parts
3. Tight blades
4. Plugged injector nozzle
5. Stuck regulating piston
6. Over tight end plate
7. Over tight delivery valve screw.

No conclusive failure mechanism for Pumps 1, 2, or 4 was attained, as none of the above sources of failure may be disproved.

As in the previous report (3), wear-prone components throughout each pump were subjectively graded from 0 to 5 according to the degree of wear present. The results are given in TABLES 3 and 4 for pumps operating on Jet A-1 and commercial diesel, respectively. Zero represents no wear, while five corresponds to severe wear or seizure. Pump 2 was almost new and showed little wear and no obvious damage. However, on each of the remaining standard (nonarctic) pumps operating on Jet A-1, the transfer section was the most severely worn area. In addition, this area of the pump appeared disproportionately worn when compared to commercial pumps operating on diesel, as summarized in TABLE 4.

Evidence of transient scuffing was visible on several transfer pump liners operated on Jet A-1. The surface of the scuffed liners was discolored and, in some instances, slightly pitted close to the fuel outlet ports, as shown in Fig. 3. The surface of a badly scuffed liner provided by the pump manufacturer is shown in Fig. 6. Considerable plastic deformation and surface pitting were present. These pits were probably formed by adhesive wear during lubricant failure and scuffing. Microscopic examination of the slightly scuffed liners from the current batch of pumps shows isolated areas with a similar but less severe wear mechanism.

The depths of the wear scars measured on the transfer pump vanes from each of the pumps are summarized in TABLE 5. The Center Line Average (CLA) surface roughness was also tabulated. Appreciably less wear was visible on transfer pumps fitted with the arctic conversion kit, probably because of the increased hardness of these parts. Significantly, both pumps fitted with the arctic conversion kits (Pumps 5 and 6) failed due to causes that could be conclusively attributed to problems other than transfer pump wear. No measurable wear was present on the transfer pump vanes from pumps operated on commercial diesel (i.e., Pumps 8, 9, and 10).

Previously (3), a wide variation in the diameter of the metering valve bore was observed among individual pumps. Loss of tolerance in this component allows fuel to pass with the valve in the off position, producing engine run on at shutdown. The manufacturing tolerance is believed to be ±0.0002 inches. The metering valve bore and spindle diameters were measured on the current batch of pumps, and the results are also included in TABLE 5. The diameter of the spindle

TABLE 3. Subjective Measure of Wear* on Critical Pump Components From Pumps Operated on Jet A-1

Component		Pump 1	2	3	4	5	6	7
Hydraulic Head & Rotor	Hydraulic Head	5	5	5	5	5	4	5
	Discharge Fittings	0	0	0	0	NA	0	1
	Distributor Rotor	5	5	5	5	5	4	5
	Delivery Valve	3	2	3	4	4	4	2
	Plungers	1	1	1	2	4	4	1
	Cam Rollers & Shoes	1	0	1	2	2	4	1
	Leaf Spring & Screw	1	1	2	3	2	3	1
	Cam	0	0	0	0	2	3	0
	Governor Weight Retainer	1	0	1	2	3	4	0
	Governor Weights	0	0	1	1	1	4	0
	Governor Thrust Washer	1	1	1	3	3	4	1
	Governor Thrust Sleeve	0	0	1	1	1	4	5
	Drive Shaft Tang		3	5	5	1	3	3
Transfer Pump	Inlet Screen (0-Clean: 5-Clogged)	0	0	3	0	3	3	4
	Regulating Adj. Plug	0	0	1	0	1	3	0
	Regulating Piston	2	1	2	3	4	5	4
	Regulator	4	2	3	2	4	4	1
	Blades	5	2	5	4	1	1	3
	Liner	4	1	4	4	2	2	3
	Rotor Retainers	2	3	2	3	4	3	1
Governor	Metering Valve	1	0	2	3	4	3	4
	Metering Valve Arm	1	0	1	1	3	3	2
Advance	Piston	1	1	4	2	3	5	3
	Cam Advance Screw	2	1	3	4	3	3	2
	Plugs	0	0	0	0	0	2	0
	Advance Bore	2	1	4	1	0	3	2
	Pivot Shaft	NA	NA	NA	NA	2	3	NA

* 0 = No Wear; 5 = Failure.
NA = Parts were not available when pump was received.

Note: Pump No. 1 = Serial No. 6594676
Pump No. 2 = Serial No. 6594864
Pump No. 3 = Serial No. 5334248
Pump No. 4 = Serial No. 6120799
Pump No. 5 = Serial No. 5806126
Pump No. 6 = Serial No. 2013101
Pump No. 7 = Serial No. 5775851

TABLE 4. Subjective Measure of Wear* From Pumps Operated on Commercial Diesel

Component		Pump No. 8	9	10
Hydraulic Head & Rotor	Hydraulic Head	0	0	0
	Discharge Fittings	0	0	0
	Distributor Rotor	0	0	0
	Delivery Valve	3	3	3
	Plungers	0	0	0
	Cam Rollers & Shoes	1	1	1
	Leaf Spring & Screw	0	0	0
	Cam	0	0	1
	Governor Weight Retainer	0	0	0
	Governor Weights	0	0	0
	Governor Thrust Washer	2	1	1
	Governor Thrust Sleeve	0	0	0
	Drive Shaft Tang	3	2	2
Transfer Pump	Inlet Screen (0-Clean; 5-Clogged)	3	2	4
	Regulating Adj. Plug	0	0	1
	Regulating Piston	2	2	2
	Regulator	1	1	1
	Blades	1	1	1
	Liner	1	1	1
	Rotor Retainers	1	1	1
Governor	Metering Valve	4	3	3
	Metering Valve Arm	1	0	1
Advance	Piston	3	3	3
	Cam Advance Screw	1	3	1
	Plugs	0	0	0

* 0 = No Wear; 5 = Failure.

Note: Pump No. 8 = Serial No. 4983254
Pump No. 9 = Serial No. 4788597
Pump No. 10 = Serial No. 5441703

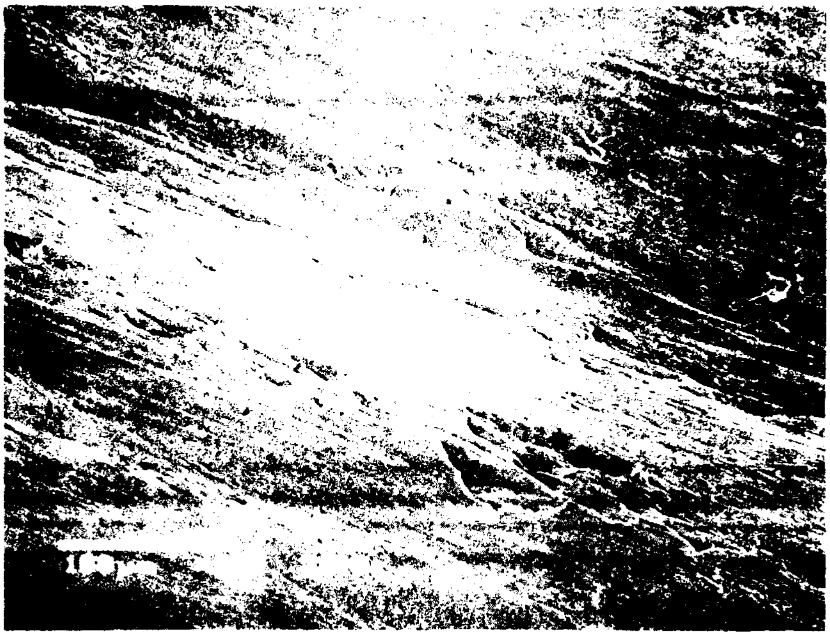


Figure 6. Scuffed surface topography on a transfer pump liner

TABLE 5. Summary of Wear on the Transfer Pump Vanes and Metering Valves

Pump No.	Wear Scar Depth, μm	Wear Scar Roughness, μm	Metering Valve Bore, in.	Metering Valve Spindle, in.
1	17	0.70	0.2514	0.2500*
2	3	0.30	0.2508	0.2497
3	32	1.29	0.2511	0.2498*
4	18	0.93	0.2508	0.2495
5	--	0.24	0.2508	0.2496
6	--	0.58	0.2504	0.2496
7	10	0.15	0.2513	0.2501*
8	--	0.25	--	--
9	--	0.20	0.2508	0.2494
10	--	0.22	0.2507	0.2496

* Denotes oversize metering valve.

should be 0.2495 and 0.2500 inches, for the regular and oversize components, respectively. The diameter of the bore should be 0.2500 and 0.2505 inches, for the regular and oversize parts, respectively.

Relatively little variation exists in the diameter of both the standard and the oversize components. The diameter of the valve bore is consistently oversize and is probably due to slight calibration error, as the oversize valve spindles would not fit into the standard bore. The diameter of worn areas on the metering valve spindles was approximately 0.0001 inch less than the remainder of the valve.

For pump seizure to occur, metallic contact must occur between the rotor and the hydraulic head. In normal operation, the rotor and the hydraulic head are separated by a thin film of fuel formed by hydrodynamic lubrication. Film formation is a dynamic process influenced by a range of parameters including viscosity, rotor clearance, and speed. The decreased viscosity of aviation fuels compared with diesel will reduce the strength of the film produced (approximately 1.1 versus 3 cSt at 40°C). In addition, the ability of kerosene fuels to resist scuffing during momentary loss of hydrodynamic film (i.e., during start up) is less than that of diesel fuels.(10) However, bench tests indicate that failure of the hydrodynamic film should not occur under normal operation.(11)

A commonly reported cause of failure associated with rotary fuel injection pumps is seizure due to rapid variation in temperature. Accelerated tests were set up using DB2 model pumps on the pump stand described in References 4 and 11. Minor modifications to the fuel supply system were made to allow rapid variation in fuel inlet temperature.

Failure could not be initiated by pumping cold fuel [50°F (10°C)] into a hot pump [180°F (82°C)]. However, immediate failure occurred when sufficiently hot fuel was passed through a cold pump. The average temperature difference between the pump and the incoming fuel required to cause seizure was found to be approximately 70°F (77°C) on six used pumps using both Jet A-1 and DF-2. No significant variation in the temperature required to cause failure was observed between the two fuels. In each instance, seizure occurred close to the transfer pump.

This seizure was caused by mechanical interference between the enlarged rotor (close to the fuel inlet) and the relatively cool hydraulic head. The increased scuffing load capabilities of diesel compared to Jet A-1 were insignificant compared with the mechanical loads involved. A more detailed description of the test procedures and results will be provided in a subsequent report specifically related to pump stand tests.

Clearly, a range of effects contributed to failure of the Stanadyne rotary fuel injection pump. Contamination and random failure of minor components were likely to have promoted a number of failures. The remaining seizures all occurred in the same location and could have been caused by a number of effects. It may be significant, however, that use of low-lubricity fuel promotes wear in an area of the pump associated with the majority of failures. Stanadyne recommends the use of the fuels detailed in TABLE 6 with the standard and arctic conversion.

Stanadyne differentiates between arctic fuels that are suitable for use and DF-1 (although the fuels are similar). Stanadyne states (13) that "arctic fuels used with the upgraded DB2 model pumps must have a viscosity of at least 1.2 centistokes at pump operating temperature [up to 140°F (60°C) return fuel temperature.] This viscosity range is likely to be below the minimum viscosity for some DF-1 fuels, as established in ASTM D 975, "Specification for Diesel Fuel Oils," (6) or ASTM D 396, "Specification for Fuel Oils" (14) as shown in TABLE 7. Jet A-1/DF-A are used year-round in Alaska; however, it is recognized that use of arctic fuel in civilian vehicles during warm weather may cause pump failure. The temperature dependence of the fuel injection system currently requires further study.

V. CONCLUSIONS

As a result of this study, the following conclusions have been reached:

1. The most common failure mechanism of the seven pumps operated on Jet A-1 was seizure of the rotor close to the transfer pump. This failure may have been initiated by a number of factors. Severe transfer pump wear caused by low-lubricity fuel **may** have been a contributing factor in some instances.

TABLE 6. Stanadyne Fuel Guidelines for the Operation of Injection Pumps
(Information taken from Reference 12.)

	Fuel Usage With Standard Components	Fuel Usage With Upgraded Components
Recommended	DF-2, No. 2-D	DF-2, No. 2-D DF-1, No. 1-D
Acceptable	DF-1, No. 1-D	No. 1, No. 2 Fuel Oil Jet A, Jet A-1, DF-A JP-5, JP-7, JP-8
Emergency	No. 1, No. 2 Fuel Oil Jet A, Jet A-1, DF-A JP-5, JP-7, JP-8 No. 4-D No. 4 Fuel Oil Jet B, JP-4	No. 4-D No. 4 Fuel Oil Jet B, JP-4

TABLE 7. Comparison of Selected Fuel Viscosities

Fuel	Kinematic Viscosity at 40°C, cSt	Kinematic Viscosity at -20°C, cSt
DF-A	1.1 to 2.4	--
DF-1	1.3 to 2.9	--
DF-2	1.9 to 4.1	--
DF-2 (OCONUS)	1.3 to 5.0*	--
JP-5 (MIL-T-5624)	1.5†	8.5
JP-8 (MIL-T-83133)	1.25†	8
Jet A-1	1.25†	8

* Kinematic Viscosity values given are equivalent to NATO requirement of 1.8 to 9.5 cSt at 20°C

† Average value from Reference 15.

2. Fuel contamination and moisture caused a significant number of failures in this and previous studies.

3. Degradation of the elastomeric flex ring and random failure of minor components such as blade springs or metering valves caused some failures.

4. Use of low-viscosity fuels reduced the strength of the hydrodynamic film around the pump rotor. However, failure of the film should not occur during normal operation.

5. Use of upgraded "arctic" components appeared to have significantly reduced wear in transfer pumps operated on Jet A-1.

6. Appreciably less transfer pump wear was seen in the transfer pump section of pumps operated on diesel fuel compared with those operated on Jet A-1.

7. The drive splines used on the DC series pumps appeared less susceptible to wear than the standard drive tang used in the DB and DB2 pumps.

8. The DB and DC series pumps should be less susceptible to wear than the standard DB2 model.

9. Transient scuffing may have occurred between the transfer pump blades and liner in pumps operated on Jet A-1.

10. The acceptability of low-viscosity/lubricity fuels is likely to be temperature dependent.

11. The addition of oil to the fuel to improve lubricity/viscosity was observed in two of the pumps, but it did not prevent pump seizure in this limited study.

12. Use of hot fuel in cold pump may promote seizure, i.e, during washing of the engine.

VI. LIST OF REFERENCES

1. U.S. Military Specification MIL-T-83133C, Turbine Fuels, Aviation, Kerosene Types, NATO F-34 (JP-8) and NATO F-35, 22 March 1990.

2. Federal Specification VV-F-800D, "Fuel Oil, Diesel," Grade DF-2, 27 October 1987.

3. Lacey, P.I. and Lestz, S.J., "Failure Analysis of Fuel Injection Pumps From Generator Sets Fueled With Jet A-1," Interim Report BFLRF No. 268, prepared by Belvoir Fuels and Lubricants Research Facility, Southwest Research Institute, San Antonio, TX, January 1991.

4. Montemayor, A.F. and Owens, E.C., "Comparison of 6.2 L Arctic and Standard Fuel Injection Pumps Using JP-8 Fuel," Interim Report BFLRF No. 218 (AD A175597), prepared by Belvoir Fuels and Lubricants Research Facility, Southwest Research Institute, San Antonio, TX, October 1986.

5. J. Swigart, Personal Communication to BFLRF Personnel, U.S. Army Tank-Automotive Command, January 28, 1990.

6. American Society for Testing and Materials Standard D 975, "Specification for Diesel Fuel Oils," 1989.

7. Roosa Master Service Bulletin No. 203, "Seizure of Head and Rotor Assemblies," January 1965.

8. U.S. Military Specification MIL-H-6083E, "Hydraulic Fluid, Petroleum Base, for Preservation and Operation," 14 August 1986.

9. U.S. Military Specification MIL-H-5606E, "Hydraulic Fluid, Petroleum Base; Aircraft, Missile, and Ordnance," 29 August 1980.

10. "Operation and Instruction Manual Model DB2 Pump," Stanadyne Diesel Systems Inc., P.O. Box 1440, Hartford, CT.

11. Lacey, P.I. and Lestz, S.J., "Fuel Lubricity Requirements for Diesel Injection Systems," Interim Report BFLRF No. 270, prepared by Belvoir Fuels and Lubricants Research Facility, Southwest Research Institute, San Antonio, TX, February 1991.

12. Stanadyne Service Bulletin No. 125R1, "Field Conversions for Low Viscosity Fuel Operation," December 1990.

13. Stanadyne Service Bulletin No. 410R1, "Conversion of DB2 Pumps for Use With Arctic Fuels," September 1985.

14. American Society for Testing and Materials Standard D 396, "Specification for Fuel Oils," 1989.

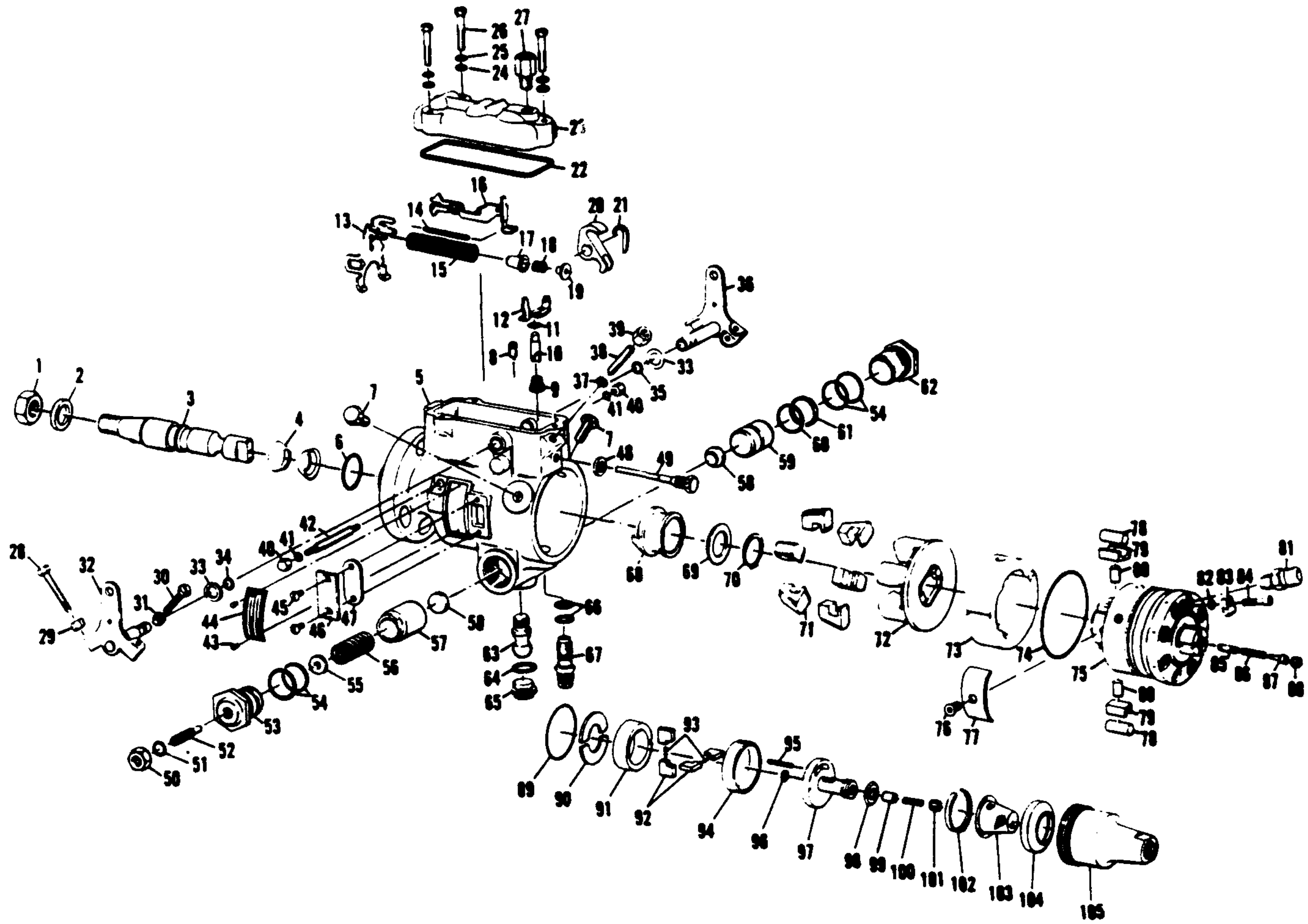
15. Bowden, J.N. and Westbrook, S.R., "A Survey of JP-8 and JP-5 Properties," Interim Report BFLRF No. 253 (AD A027721), prepared by Belvoir Fuels and Lubricants Research Facility (SwRI), Southwest Research Institute, San Antonio, TX, September 1988.

LIST OF ABBREVIATIONS

Belvoir RDE Center	-	U.S. Army Belvoir Research, Development and Engineering Center
BFLRF	-	Belvoir Fuels and Lubricants Research Facility (SwRI)
BOCLE	-	Ball-on-Cylinder Lubricity Evaluator
CLA	-	Center Line Average
CONUS	-	Continental United States
CUCV	-	Commercial Utility Cargo Vehicle
DB	-	Series designator of Stanadyne rotary fuel injector pump
DB2	-	Series designator of Stanadyne rotary fuel injector pump
DC	-	Series designator of Stanadyne rotary fuel injector pump
DF-A	-	Diesel Fuel, Arctic
DF-1	-	Diesel Fuel, Grade DF-1
DF-2	-	Diesel Fuel, Grade DF-2
HMMWV	-	High Mobility Multipurpose Wheeled Vehicle
HRC	-	Rockwell Hardness Value
MEP	-	Mobile Electric Power
OCONUS	-	Outside Continental United States
SEM	-	Scanning Electron Microscope
SwRI	-	Southwest Research Institute

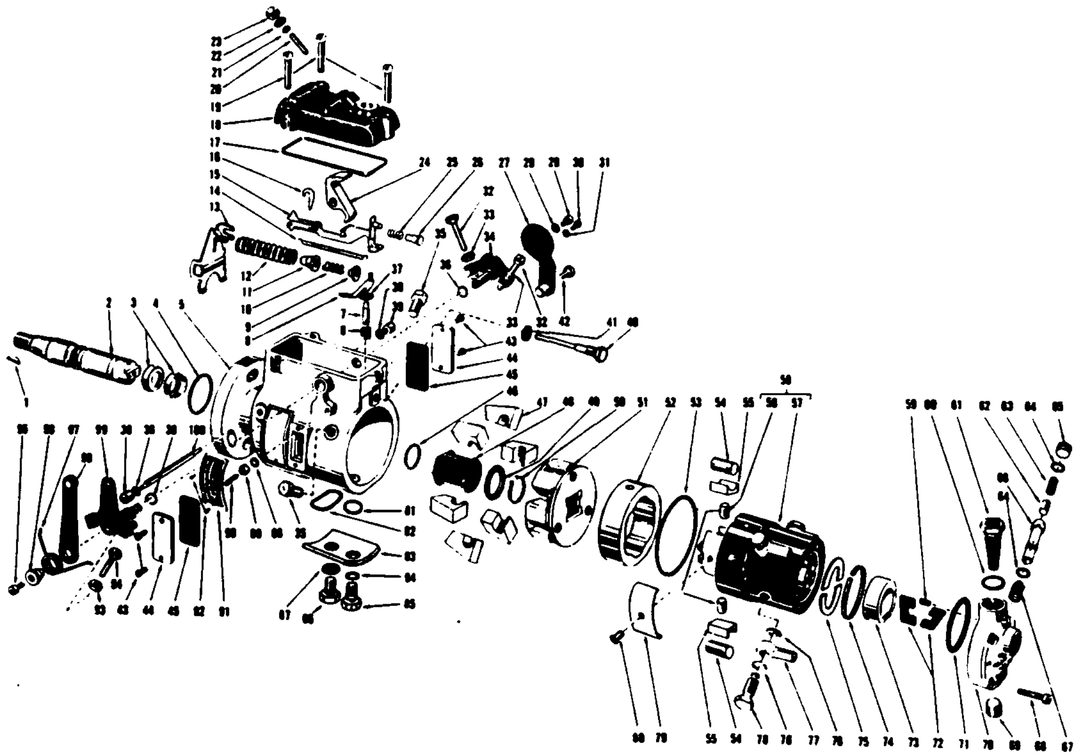
APPENDIX A

Diagrams of Stanadyne Pump Series



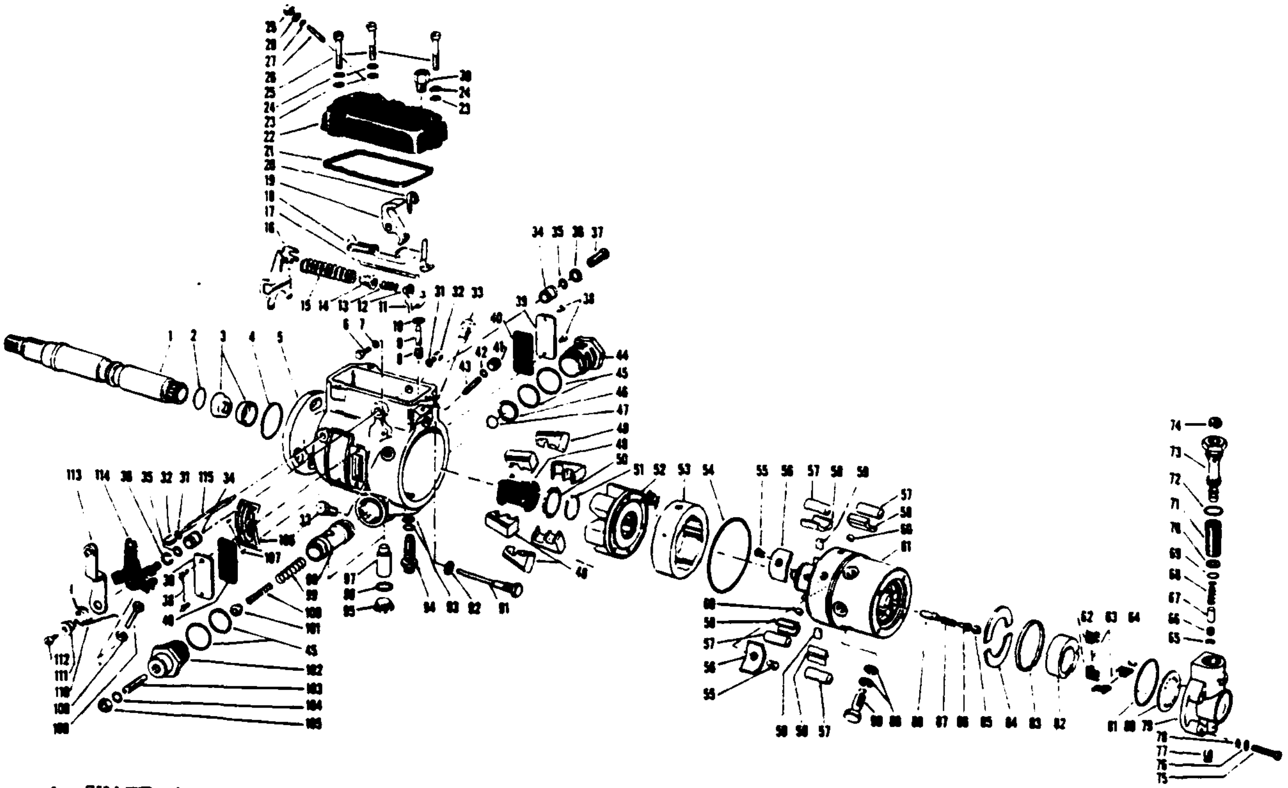
1. NUT, drive shaft
2. WASHER, drive shaft
3. SHAFT, drive
4. SEAL, drive shaft
5. HOUSING ASSY., pump
6. SEAL, pump flange
7. SCREW, head locking
8. SCREW ASSY., vent
9. SPRING, metering valve
10. VALVE, metering
11. SHIM, metering valve
12. ARM ASSY., metering valve
13. ARM, governor
14. SPRING, linkage hook
15. SPRING, governor
16. LINKAGE ASSY., gov. hook adj.
17. RETAINER, spring
18. SPRING, idling
19. GUIDE, idling spring
20. LEVER, throttle shaft
21. CAM, shut-off
22. GASKET, governor cover
23. COVER, governor control
24. WASHER, cover screw
25. LOCK WASHER, cover screw
26. SCREW, cover hold-down
27. CONNECTOR ASSY., return line
28. SCREW, low idle adjusting
29. NUT, low idle screw
30. SCREW, high idle adjusting
31. NUT, high idle screw
32. SHAFT ASSY., throttle
33. WASHER, throttle shaft seal
34. SEAL, throttle shaft
35. SEAL, shut-off shaft
36. SHAFT ASSY., shut-off
37. SEAL, torque screw
38. SCREW, torque
39. NUT, torque screw
40. NUT, pivot shaft
41. SEAL, pivot shaft
42. SHAFT, gov. arm pivot
43. SCREWS, nameplate
44. PLATE, name
45. SCREW, timing line cover
46. COVER, timing line
47. GASKET, timing line cover
48. WASHER, guide stud
49. STUD, guide
50. NUT, adv. adj. screw
51. SEAL, adv. adj. screw
52. SCREW, advance adjusting
53. PLUG, piston hole (trimmer side)
54. SEAL, piston hole plug
55. GUIDE, adv. adj. spring
56. SPRING, advance adjusting
57. PISTON, spring
58. WASHER, slide
59. PISTON, power
60. SEAL, piston ring
61. RING, piston
62. PLUG, piston hole (power side)
63. SCREW, cam advance
64. SEAL, advance screw hole plug
65. PLUG, advance screw hole
66. SEAL, head locating screw
67. SCREW, ASSY., head locating
68. SLEEVE, governor thrust
69. WASHER, gov. thrust sleeve
70. RING, gov. cage retaining
71. WEIGHT, governor
72. RETAINER ASSY., gov. weight
73. CAM RING
74. SEAL, hydraulic head
75. HEAD AND ROTOR ASSY.
76. SCREW, leaf spring
77. SPRING, leaf
78. ROLLER, cam
79. SHOE, cam roller
80. PLUNGERS
81. FITTING, discharge
82. SEAL, locking plate
83. PLATE, locking
84. SCREW, locking plate
85. VALVE, delivery
86. SPRING, delivery valve
87. STOP, delivery valve
88. SCREW, delivery valve
89. SEAL, transfer pump
90. RETAINERS, rotor
91. LINER, transfer pump
92. BLADES, transfer pump
93. SPRINGS, transfer pump blade
94. RING, liner locating
95. ROLLPIN, regulator
96. SEAL, inlet filter screen
97. REGULATOR ASSY., transfer pump
98. SEAL, inlet filter screen
99. PISTON, regulating
100. SPRING, regulating
101. PLUG ASSY., end plate adjusting
102. RING, filter screen retaining
103. SCREEN, inlet filter
104. PLATE, transfer pump pressure
105. CAP, transfer pump end

Figure A-1. Exploded diagram of the Stanadyne DB2 series pump
(Figure A-1 presented in "Operation and Instruction Manual DB2 Pump," Stanadyne Diesel Systems, Inc., P.O. Box 1440, Hartford, CT.)



1. KEY, drive shaft
2. SHAFT, drive
3. SEAL, drive shaft
4. SEAL, pilot tube
5. HOUSING ASSEMBLY, pump
6. SPRING, metering valve
7. VALVE, metering
8. ARM ASSEMBLY, metering valve
9. GUIDE, idling spring
10. SPRING, idling
11. RETAINER, spring
12. SPRING, governer control
13. ARM, governer
14. SPRING, governer linkage
15. HOOK ASSEMBLY, governer linkage
16. CAM, shut-off
17. GASKET, control cover
18. COVER, governer control
19. SCREW, cover hold-down
20. SCREW, low idle adjusting
21. SEAL, low idle adj. screw
22. WASHER, low idle adj. screw
23. NUT, low idle adj. screw
24. LEVER, throttle shaft
25. SPRING, damper
26. SLEEVE, damper
27. LEVER ASSEMBLY, adj. shut-off
28. LOCKWASHER, adj. shut-off lever ret. screw
29. SCREW, adj. shut-off lever retaining
30. SCREW, adj. shut-off lever positioning
31. LOCKWASHER, adj. shut-off lever pos. screw
32. SCREW, shut-off lever adjusting
33. NUT, adjusting screw
34. SHAFT ASSEMBLY, shut-off
35. SCREW, head locking
36. SEAL, shaft
37. SHIM, metering valve
38. SEAL, pivot shaft
39. NUT, pivot shaft retainer
40. STUD, guide
41. WASHER, guide stud
42. SCREW, stop lever fitting
43. SCREW, timing line cover
44. COVER, timing line
45. GASKET, timing line cover
46. RING, drive shaft retaining
47. WEIGHT, governer
48. SLEEVE, governer thrust
49. WASHER, governer sleeve thrust
50. RING, governer cage retaining
51. RETAINER ASSEMBLY, governer weight
52. CAM RING
53. SEAL, hydraulic head
54. ROLLER, cam
55. SHOE, cam roller
56. PLUNGER, rotor
57. HEAD AND ROTOR, hydraulic
58. HYDRAULIC HEAD AND ROTOR ASSEMBLY
59. ROLLPIN, end plate locating
60. SEAL, filter cap
61. CAP & FILTER ELEMENT ASSEMBLY
62. PISTON, regulating
63. SPRING, regulating
64. SEAL, end plate sleeve
65. PLUG, end plate
66. SLEEVE, end plate
67. SPRING, plunger retaining
68. SCREW, end plate
69. PLUG, end plate pipe
70. PLATE, end
71. SEAL, transfer pump
72. BLADE, transfer pump
73. LINER, transfer pump
74. RING, rotor retainer
75. RETAINER, rotor
76. WASHER, fuel line connector screw
77. CONNECTOR, fuel line
78. SCREW, fuel line connector
79. SPRING, leaf
80. SCREW, leaf spring adjusting
81. SEAL, head locating screw
82. SEAL, cam hole
83. PLATE, cam locating
84. SEAL, head locating screw
85. SCREW, head locating
86. SCREW, cam locating
87. WASHER, cam locating screw
88. SEAL, torque screw
89. NUT, torque screw
90. SCREW, torque
91. PLATE, name
92. SCREW, name plate
93. NUT, high idle adjusting screw
94. SCREW, high idle adjusting
95. SCREW, throttle lever retaining
96. RETAINER, throttle lever spring
97. SPRING, throttle lever
98. LEVER ASSEMBLY, throttle shaft
99. SHAFT ASSEMBLY, throttle
100. SHAFT, governer arm pivot

Figure A-2. **<u>Exploded diagram of the Stanadyne DB model pump</u>**
(Figure A-2 presented in "Operation and Instruction Manual DB Pump," Stanadyne Diesel Systems, Inc., P.O. Box 1440, Hartford, CT.)



1. SHAFT, drive
2. RING, drive shaft
3. SEAL, drive shaft
4. SEAL, pilot tube
5. HOUSING ASSEMBLY
6. SCREW, torq. scr. hole plug
7. WASHER, torq. screw hole
8. SPRING, metering valve
9. VALVE, metering
10. SHIM, metering valve
11. ARM ASSY., metering valve
12. GUIDE, idling spring
13. SPRING, idling
14. RETAINER, spring
15. SPRING, governor control
16. ARM, governor
17. SPRING, governor linkage
18. HOOK ASSEMBLY, governor linkage
19. LEVER, throttle shaft
20. CAM, shut-off
21. GASKET, governor cover
22. COVER, governor control
23. WASHER, cover hold-down screw
24. LOCKWASHER, cover screw
25. SCREW, cover hold-down
26. SCREW, low idle adj. scr.
27. SEAL, low idle screw
28. WASHER, low idle adj. scr.
29. NUT, low idle adj. screw
30. CONNECTOR ASSY., return line
31. SEAL, pivot shaft
32. NUT, pivot shaft retainer
33. SCREW, head locking
34. BUSHING, throttle shaft
35. SEAL, throttle shaft
36. WASHER, throttle shaft seal
37. SHAFT, shut-off
38. SCREW, timing line cover
39. COVER, timing line
40. GASKET, timing line cover
41. NUT, torque screw
42. SEAL, torque screw
43. SCREW, torque
44. PLUG, piston (power)
45. SEAL, adv. piston hole plug
46. RING, adv. piston
47. SEAL, piston ring
48. WEIGHT, governor
49. SLEEVE, governor thrust
50. WASHER, gov. thrust sleeve
51. RING, gov. cage retaining
52. RETAINER ASSY., weight
53. CAM RING
54. SEAL, hydraulic head
55. SCREW, leaf spring adj.
56. SPRING, leaf
57. ROLLER, cam
58. SHOE, cam roller
59. PLUNGER, rotor
60. PLUNGER, rotor
61. HEAD AND ROTOR, hydraulic
62. BLADE, transfer pump
63. SPRING, trans. pump blade
64. ROLLPIN, end plate loc.
65. RING, retaining
66. SEAL, regulating piston
67. PISTON, regulating
68. SPRING, regulating
69. RING, sleeve seal
70. SEAL, element
71. ELEMENT, filter
72. SEAL, end plate sleeve
73. SLEEVE, end plate
74. PLUG ASSY., end plate adj.
75. SCREW, end plate
76. LOCKWASHER, end plate screw
77. PLUG, end plate pipe
78. WASHER, end plate screw
79. PLATE, end
80. PLATE, thrust
81. SEAL, transfer pump
82. LINER, transfer pump
83. RING, rotor retainer
84. RETAINER, rotor
85. SCREW, delivery valve ret.
86. STOP, delivery valve
87. SPRING, delivery valve
88. VALVE, delivery S. B. 109
89. WASHER, fuel line connector
90. SCREW, fuel line connector
91. STUD, guide
92. WASHER, guide stud
93. SEAL, head loc. screw
94. SCREW ASSY., head loc.
95. PLUG, adv. scr. hole
96. SEAL, adv. scr. hole plug
97. PIN, advance
98. PISTON, advance
99. SPRING, outer advance
100. SPRING, inner advance
101. GUIDE, adv. adj. screw
102. PLUG, piston (spring)
103. SCREW, advance adj.
104. SEAL, adv. adj. screw
105. NUT, adv. adj. screw
106. PLATE, name
107. SCREW, name plate
108. SCREW, throttle lever stop
109. NUT, throttle lever stop scr.
110. SPRING, throttle lever
111. RETAINER, throttle lever spr.
112. SCREW, throttle lever spring
113. LEVER ASSY., throttle
114. SHAFT ASSY., throttle
115. SHAFT, governor arm pivot

Figure A-3. Exploded diagram of the Stanadyne DC model pump
(Figure A-3 presented in "Operation and Instruction Manual DC Pump," Stanadyne Diesel Systems, Inc., P.O. Box 1440, Hartford, CT.)

APPENDIX B

Gas Chromatographic Analysis

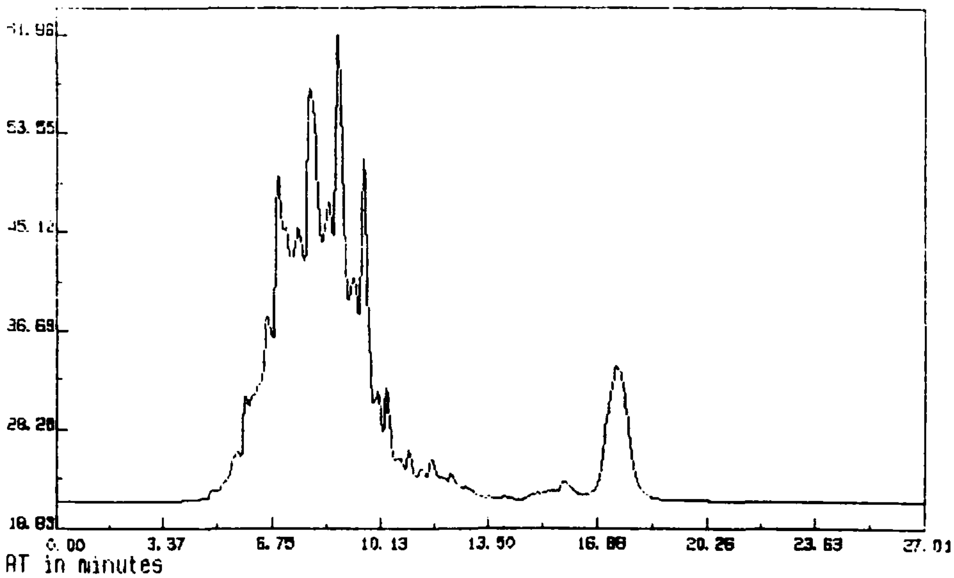


Figure B-1. <u>**Traces from gas chromatographic analysis of sample from pump**</u>

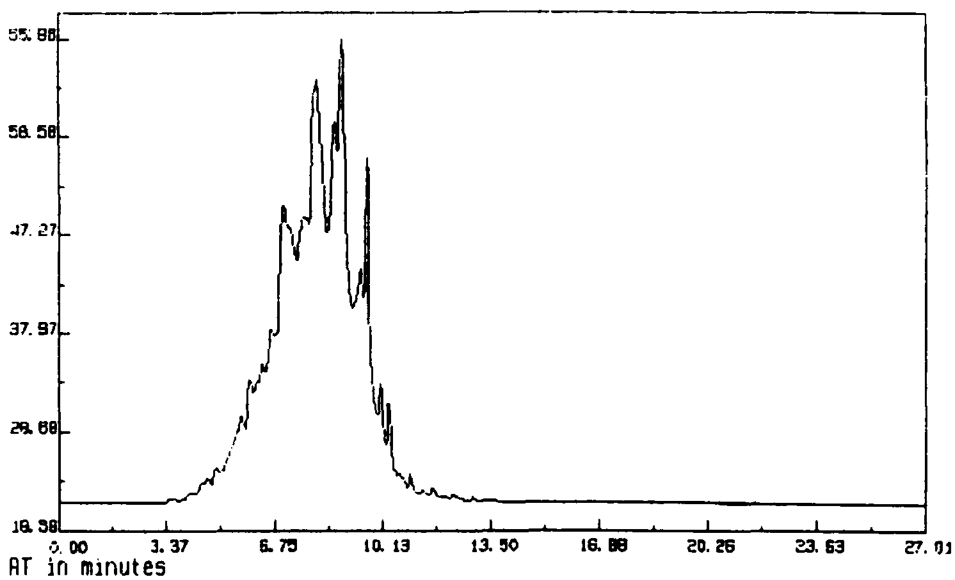


Figure B-2. <u>**Traces from gas chromatographic analysis of typical Jet A-1/JP-8**</u>

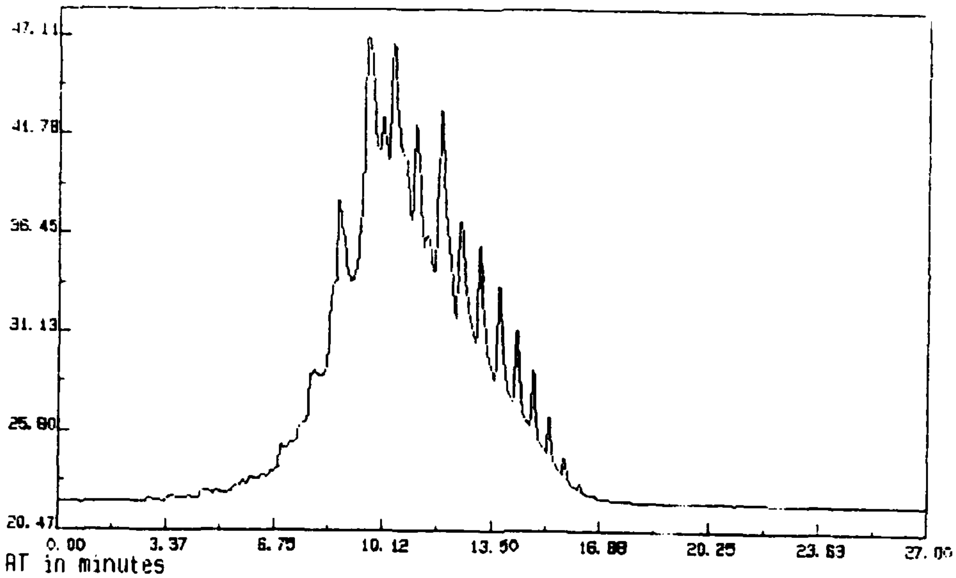


Figure B-3. <u>Traces from gas chromatographic analysis of typical diesel fuel</u>

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